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Sediment deposition within two Thalassia testudinum seagrass sites in Boca del Drago, Bocas del Toro Archipelago, Panamá

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SIT Study Abroad

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Title

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Introduction

Outlining Seagrass Beds and Habitat Distribution

Seagrass meadows are considered highly productive, shallow marine habitats that span subtropical and tropical zones worldwide, and facilitate a multitude of functions across the dynamic connection between terrestrial and oceanic ecosystems (López-Calderón et. al. 2013). This ecological position makes seagrass habitats a repository for sediments and nutrients from multiple sources and directions. The seagrass *Thalassia testudinum* is an aquatic angiosperm plant species centralized within the Caribbean Sea, and is strongly associated with the shallower regions that precede Caribbean coral reef environments (Van Tussenbroek et. al. 2014). *Thalassia testudinum*, like other seagrasses, is within the small family of aquatic flowering plants (Alismatidae) that makes up only 2 percent of all Angiosperm species. This species occupies prolific areas of coastal Caribbean substrate due to having sexual reproduction and dispersal through pollination of aquatic flowers (hydrophily), as well as fast clonal reproduction from rhizomatic colonies (Les et. al. 1997).

While *T. testudinum* and other seagrasses have a large area of distribution globally, the low taxonomic diversity of the family leaves homogeneous seagrass beds more vulnerable to mass displacement and degradation (Orth et. al. 2013). Due to the intensification of anthropogenic environmental stressors at different biochemical and ecological levels, seagrass habitats have experienced escalating losses worldwide. Global losses of seagrass habitats were calculated to be about 110 km^2/yr in present years compared to 27 km^2/yr average losses for the last 30 years (López-Calderón et. al. 2013). Losses at this large-scale force other organisms within these ecosystems to adapt dramatically to the changing conditions within this habitat, and species that are not resilient enough to endure these changes can be lost as well. In the Caribbean, declining seagrass health has served as a bioindicator for the strength of coastal ecology, and researching ways seagrasses both mitigate and receive environmental disturbances is critical in order to understand proper ways to conserve these systems (Van Tussenbroek et. al. 2014).

Geographic and Environmental Conditions of Bocas del Drago, Bocas del Toro Archipelago

Bocas del Toro is an archipelago in the upper northwest of Panamá, that encompasses the Bahía Almirante Lagoon on the Caribbean Sea (Kaufmann and Thompson 2005). Boca del Drago is a populated, beachfront coastal region in the northwest of Isla Colón, the northernmost island in the archipelagic chain. This geographic position means Boca del Drago is exposed to sediment and nutrients moving both westward from the currents of the Caribbean Sea, as well as in terrestrial runoff from Isla Colón and continental Panamanian sediments flowing from Bahía Almirante. The inshore waters of Bahía Almirante have also been found to retain slightly more heat than ocean-facing zones. In a comparison of annual water temperature trends, mean inshore temperatures were about 2°C warmer in summer/wet season months than winter/dry season months, while mean oceanic temperatures differed by about 1.1°C between these two seasons (Kaufmann and Thompson 2005). Since Boca del Drago is at the intersection of the bay and open sea, studying field sites on opposite sides of the region could show how seagrass bed health, and sedimentation inputs change under these potentially different physical conditions.

Terrestrially, the Bocas del Toro Archipelago is extensively covered with mangrove forests, almost completely dominated by *Rhizophora mangle* (Lovelock et. al. 2005). *R. mangle* that line the Bocas del Toro coast are on average 3-5 m high, and the majority of the intertidal interior contains dwarf mangrove forest (Lovelock et. al. 2005). Dwarf interior forests of *R. mangle* are particularly susceptible to being cleared for human economic and residential development (Lovelock et. al. 2005). Mangrove habitats provide a critical ecosystem service by retaining rich soil organic matter within peat bogs, and mangrove removal disables this ecosystem service for the surrounding area (Granek & Ruttenberg 2008). In a study of mangrove forests that faced Bahía Almirante, sedimentation into coastal zones containing seagrass was higher in areas where mangroves were historically cleared versus intact (Granek & Ruttenberg 2008). These cleared mangrove areas also brought less organic carbon in runoff (Granek & Ruttenberg 2008). Furthermore, the central cordillera of Panamanian mountains divert most terrestrial runoff into the Laguna de Chiriquí directly south of Bocas del Toro, making the watershed of Almirante Bay more localized (Kaufmann and Thompson 2005). Due to this restricted area of terrestrial runoff that the seagrass shorelines of Boca del Drago catch, sediment movement can be related more directly to surrounding habitat conditions that regulate the flow of freshwater runoff.

Seagrass Ecosystem Services

Seagrass beds have multifaceted ecosystem services that first range from providing habitat and food sources to migratory species, nurseries for juvenile fish/invertebrate species that are often commercial, and by hosting small epiphyte organisms on leaf cover (Orth et. al. 2013). Seagrasses are also important blue carbon sinks that sequester 15% of oceanic organic carbon (López-Calderón et. al. 2013). Prominent Caribbean species like *Thalassia testudinum* have a significant amount of rhizomatic below-ground biomass that not only hold carbon in living tissues, but also retain soil organic matter in conditions that limit aerobic decomposition (López-Calderón et. al. 2013). In the Western Caribbean, *T. testudinum* seagrasses commonly act as buffers between terrestrial mangrove forests and oceanic habitats, by receiving and processing organic matter and nutrient runoff. *T. testudinum* has high rates of growth and productivity that capture the majority of carbonic soils and nutrients flowing in from land, and this action allows clearer waters to reach sensitive coral reefs (Van Tussenbroek et. al. 2014). This service supports coral reefs and the diverse fauna they house by leaving coral polyps less stressed from turbid water quality, while limiting the nutrients that opportunistic algae could utilize to outcompete corals. Seagrasses have also been recorded to regulate and rebuild sediment surface elevation. These species interact with the equilibrium between above-ground sediment deposition and erosion, by influencing how currents and materials move through beds of standing green seagrass tissue (Potouroglou et. al. 2017). At the same time, these seagrasses impact below-ground soil movements, both by strengthening soils against island subsidence, and by opening and weakening soils through root growth (Potouroglou et. al. 2017). Additionally, seagrass meadows worldwide provide important ecosystem services by mitigating wave energy and coastal flooding, and these ecological ideas can be integrated into problems that are largely thought of from a synthetic engineering perspective. Based on the length and width of seagrass blades, combined with the density of the crop in a given environment, seagrass beds can provide coastal defense by dissipating wave energy, creating friction, and reflecting energy back offshore (Ondiviela et. al. 2014). Calculating seagrass density can also be applied to understanding the ability for seagrass shoots to collide with inflowing sediments and cause them to deposit in the seagrass substrate.

Disturbances, Stressors, and Resilience of Seagrasses

While seagrasses provide many versatile and beneficial ecosystem functions, they are also negatively impacted by many multivariable processes. *Thalassia testudinum* meadows are being cleared on the Caribbean coast for expansion of human infrastructural development, land expansion, and tourism industries (López-Calderón et. al. 2013). At the same time, terrestrial land clearance alters the dense mangrove habitat usually associated with seagrasses, and therefore changes the intensity and composition of sediments the meadow receives. The Bocas del Toro Archipelago is not directly in the hurricane belt, but northern hurricanes within the Gulf of Mexico often induce high rainfall and terrestrial flooding in the area (Lovelock et. al. 2005). With periods of intense weather disturbances increasing due to climatic change, as well as vegetated habitats being cleared, seagrasses are now susceptible to unprecedented amounts of sedimentary erosion and nutrient runoff from freshwater sources (Orth et. al. 2013; Van Tussenbroek et. al. 2014). Descriptive studies and experimental simulations have shown hurricanes can move large amounts of sediment that reach depository heights that can bury and kill standing above-ground seagrass. Many small seagrass species are unable to adapt and survive through these intense periods (Cabaço et. al. 2008). With more runoff comes more nutrients, and four new opportunistic species of macroalgal were also shown to become epiphytes on *Thalassia testudinum* at the Caribbean Colombian island of San Andres (Albis-Salas & Gavio 2011). This findings could signal a broader trend of more algae extending the range they grow and the habitat niches they occupy. Increased algal competition on the leaf surface, as well as increased water turbidity, both limit the amount of sunlight seagrass shoots can photosynthesize and cause more seagrass leaf tissues to rot and degrade (Newell & Koch 2004). But these physical and biochemical stressors are not completely overwhelming, as *Thalassia testudinum* was shown to be the most resilient seagrass to sediment burial, due to its robust and partially vertically-extending rhizomes allowing greater colony survival and regeneration (Cabaço et. al. 2008). Understanding the extent of sediment deposition, as well as sediment retention, within seagrasses are critical indicators that can be used to visualize the dynamics between sediment movement and seagrass health.

Further Research and Justification for Study

Preliminary research literature showed that seagrasses provide important ecosystem services that both influence and are influenced by sediment movement. This relationship can be measured in a variety of ways. Studies carried out in the Bocas del Toro region focused on seagrass health as determined by *Thalassia testudinum's* growth rate, biomass production, and productivity, with a focus on carbon sequestration (López-Calderón et. al. 2013; Van Tussenbroek et. al. 2014). While Granek & Ruttenberg analyzed sedimentation in areas of Bocas del Toro, mangrove forest composition was the primary variable that was compared, and seagrass was not studied in depth (2008). Extensive research on seagrass and sedimentation has been carried out in Europe and the North Atlantic, which harbor different seagrass species than those found in the Caribbean (Ondiviela et. al. 2014; Newell & Koch 2004). It is pertinent to engage in research that analyzes the amount of sediment deposition in relation to *Thalassia testudinum* seagrass bed health and density, with regard to the unique geographic and environmental circumstances Boca del Drago experiences in the Bocas del Toro Archipelago.

Research Question

Does sediment deposition and composition differ between front and back areas of *Thalassia testudinum* seagrass beds within two sites on the coast of Boca del Drago, and do these two distinct sites have differences in relative seagrass density and above-ground biomass?

Research Objective

Understand how sediment deposition and sediment composition compare between front and back seagrass areas within two *Thalassia testudinum* seagrass meadows on the coast of Boca del Drago, and whether the density and above-ground biomass of seagrass identified in each of these two distinct sites also differs.

Methods

The two seagrass sites chosen for study had their geographic location analyzed, broadly distinguishing notable habitat factors in the immediate coastal area using applications like Google Maps and GPS Location (as well as personal visual observations). A commonly used method for measuring sediment deposition over a period of time involves constructing vertically-oriented benthic sediment traps (Krause-Jensen et. al. 2004). Sediment traps were constructed out of PVC pipes that were 2-inches in diameter. These pipes were 40 cm, in order to be higher than the vertical length of the *Thalassia testudinum* blades (Pers. comm. 2018). Individual pipes were fastened vertically in the seagrass meadow using a rebar connected to the outside of the pipe with cable ties. The bottom of the pipe was capped while the top of the pipe was left opened to allow sediment to flow in for 5 days (Pers. comm. 2018). The exact times of pipe trap set-up and collection of sediments after 5 days were recorded. Simultaneous repetitions of sediment traps were performed to increase validity and unbiased nature of data collection, and each trial at each site contained 3 sediment traps. Two parallel trials of sediment traps were established at each site, each containing one group of pipes that was at the front of the seagrass beds close to shore, to measure incoming terrestrial sediment runoff in the area. These front sediment traps were then compared to another trial farther within the seagrass bed, as a measure of how much sediment still remained after moving through and potentially being retained in this area of the seagrass meadow. Sediment traps placed in the "front area" of the seagrass were placed 15 m into the interior of the seagrass meadow, measured from where the seagrass bed began. "Back area" sediment traps were then placed an additional 15 m behind the corresponding group of pipes named the "front area." This entire parallel trial structure was replicated once within each of the two seagrass sites, meaning 2 front seagrass trials and their 2 corresponding back seagrass trials were established at each site. This amounted to 12 pipes at each site for a total of 24 pipe sediment traps. Parallel trials were placed 10 m apart from each other. Once sediment traps were collected, these pipes were placed in a still area and allowed to rest overnight so that sediment particles settled and only suspended material remained in the water column (about 15 hours). The next day the pipes were drained into a coffee filter supported by a dry sieve to filter the sediments out of the water. Sediment composition was noted qualitatively for color, relative grain size, and the type of sediment matter contained within each pipe (ie. identifying organic matter or fine sand), and mass was measured to calculate wet weight in grams (Falco et. al. 2000). The sifted samples were then dried for about 24 hours before dry weight, in grams, was measured. A secchi disk was used to measure water turbidity as a representation of suspended oceanic sediments in the area, taken on the day of pipe collection (Van Tussenbroek et. al. 2014). At each site, the location's weather conditions were also recorded on the day of placement and retrieval of various types of data, to show the environmental conditions that could influence sediment runoff or directly impact seagrass.

Seagrass density was calculated by sampling seagrass individuals that fit within a 20cmx10cm quadrat, taken at random preselected intervals on a transect (Newell & Koch 2004). At each site, two 10 m transects were placed within 3 meters parallel to each of the two sets of seagrass pipes, one transect associated with the front seagrass pipes and one associated with the back seagrass pipes. 3 quadrats counting seagrass shoots were done on each transect, placed at the preselected random intervals of 3 m, 5 m, and 9 m. After individual shoots were counted within each quadrat, they were collected from the quadrats using scissors and left to dry for 3 days. Dried *T. testudinum* samples were cut at the transitional growth band between green and white leaf tissue, and the green tissue was measured in grams to estimate above-ground biomass from the area within these quadrat samples (López-Calderón et. al. 2013; Van Tussenbroek et. al. 2014). Additionally, epiphyte coverage at each site was measured by randomly selecting an equal amount of 5 *T. testudinum* shoots from each site, within the region between the front and back sediment pipes. The leaves of these seagrass shoots were measured for total blade lengths, widths to calculate leaf area, and the length of blade from the first epiphyte seen (Van Tussenbroek et. al. 2014).

For the sediment analysis, data was collected on the mass of each sediment sample (wet and dry weight in g) to calculate averages, and also qualitative observations of sediment size and physical characteristics after sifting. Secchi disks measured water turbidity using the distance of visibility measured between the diver and disk. *T. testudinum* seagrass density was calculated based on individuals per square meter, extrapolated from the multiple quadrat measurements on each transect. For the survey of seagrass habitats, dry weight of green tissue (g) was collected to estimate above-ground biomass. Epiphyte coverage was quantified through average blade lengths, estimated leaf area per site, and average epiphyte coverage per site. Microsoft Excel was used to create graphs and also use statistical analysis such as two-sample t-tests to compare averages between front and back trials and between sites.

Unexpected conditions in the field caused some alterations to how and when methods were performed. For example, measuring water turbidity with the secchi disk that was provided is usually done by collecting water in a vertical glass column with the secchi disk inside, looking into the cylinder from above. The diver is then able to measure the distance it takes for the secchi disk to be obscured by the water column. However, the water quality at both sites identified in Boca del Drago had visibility that was larger than the maximum 0.6 m that the vertical secchi tube could measure. Distance of secchi disk visibility was then measured using improvised horizontal techniques to measure how far a diver could see underwater. Therefore, estimations of visible distance were provided in the results of this research to provide greater understanding of the site, but these were made using methods that were not ideal.

Ethics

Pipes used for sediment collection were established in two seagrass sites for 5 days, resting on top of the substrate and fastened with a thin metal rebar in a way that does not require intense disturbances of the coastal sediment or require the seagrass to be cleared or damaged. Because these pipes are 40 cm, and slightly larger than the *Thalassia testudinum* shoots themselves, they should not fully obstruct light from individuals and harm their photosynthetic capability or growth in the short period of time they are within the seagrass bed. For this study, only above-ground biomass was used and seagrass shoots were partially removed within the 6 quadrats at each site, but this method does not fully kill the plant and new seagrass can easily regenerate and grow into the area from remaining tissue connected to the rhizome (Cabaço et. al. 2008). An additional method of measuring below-ground biomass requires a sediment core to be taken with a pipe that is six inches in diameter, but this method leaves a hole or 'scar' in the seagrass bed substrate that takes a significant amount of time to refill and can kill surrounding plants in the rhizomatic colony (Van Tussenbroek et. al. 2014). Taking this into consideration, the above-ground method, and a very brief sampling of random shoots with epiphyte coverage, were the only extractions of living biomass from the seagrass sites.

Results

Geographic Site Description

Site 1 was identified as a seagrass bed facing a coastline populated by a dense *Rhizophora mangle* mangrove forest (Figure 1). This site is positioned at the farthest Southeastern edge of Playa Estrella. Playa Estrella is a high human-impact site that has had its forested beachfront cleared and developed for daily tourism, swimming, and boating. Site 1 is positioned where the natural curvature of the coastline turns away from the developed beachfront and waves move toward the more eastern mangrove forest (Figure 2). This seagrass site is also positioned on the side of Boca del Drago and Isla Colón that receives the majority of its water currents from the interior of Bahía Almirante. Major terrestrial inputs of runoff and sedimentation include organic matter moving out of the immediate mangrove forest due to intertidal flooding, as well as runoff and erosion from the nearby beachfront moving into this site through tidal energy (Figure 1).

Site 2 was identified as a wide seagrass bed adjacent to beachfront shoreline within the northern coast of Boca del Drago (Figure 3). The coastline is loosely populated by 5-6 families whose houses face this small bay (medium human-impact). As such, the terrestrial coastal forest has been partially cleared for the development of these homes and the road that services them. No mangrove forests were encountered in the immediate area. This site on the northern portion of Boca del Drago receives oceanic wave currents coming from the Caribbean Sea rather than Bahía Almirante (Figure 1). Freshwater inputs of terrestrial runoff also move into the coastal oceanic waters through two streams that feed into this bay slightly to the south of this seagrass site (Figure 1).

Figure 1: Aerial view of the two seagrass sites studied in Boca del Drago, using satellite imagery, and displaying notable sources water movement and runoff that can bring sediment into the area.

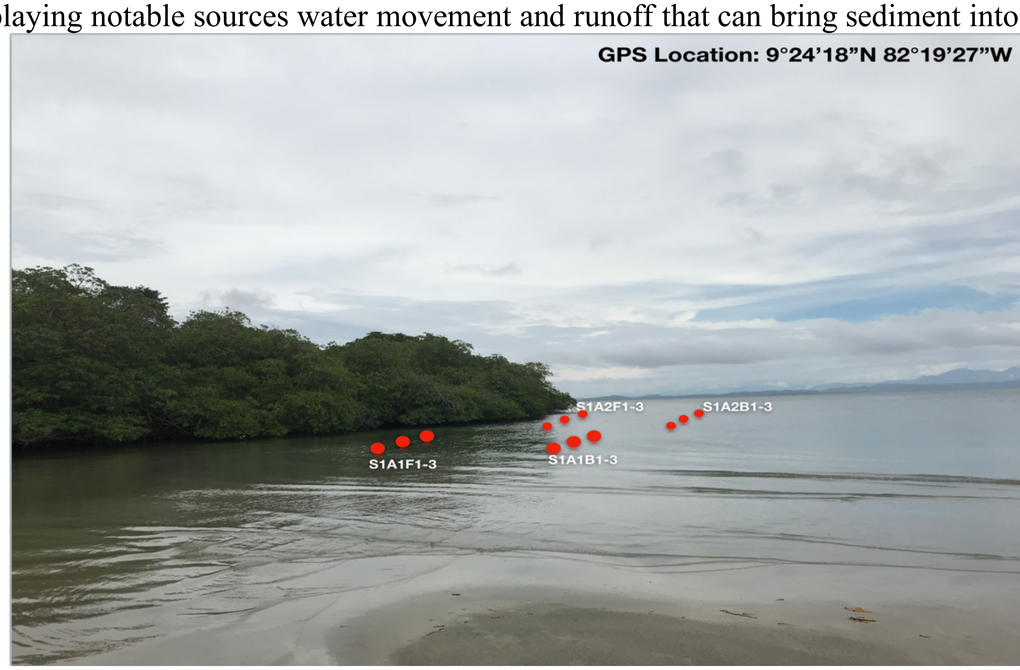

Figure 2: Photo of Site 1 seagrass from the coast, overlaid with sediment pipe trials. Front pipes were established closest to the mangrove coast, back pipes were deeper in the seagrass center.

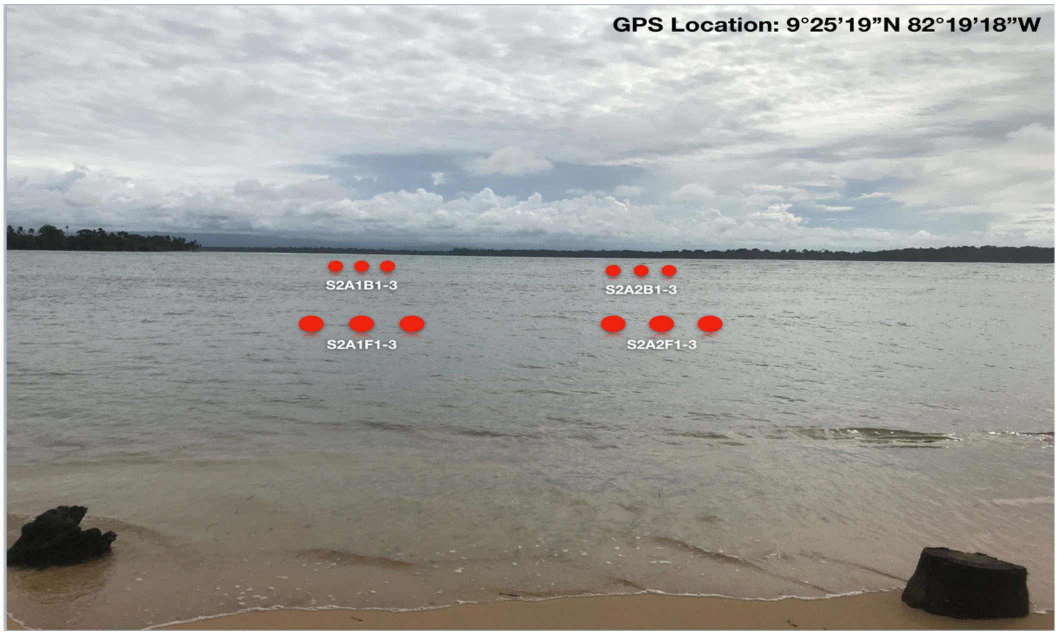

Figure 3: Photo of Site 2 seagrass from the coast, overlaid with sediment pipe trials. Front pipes were established in parallel trials in the foreground, back pipes were deeper in the seagrass center.

Environmental Characteristics

Daily weather was recorded and compiled from field observations from June 22 to June 27. These were the days pipe sediment traps were established and collecting sediments. Of these 6 days where weather was recorded, 5 days had clear sunny weather interrupted by significant rain showers (Figure 4). Three of these days had thunderstorms, and 2 of these thunderstorms continued throughout the night. Wave energy during the day was also qualitatively observed to be consistently more intense at Site 2 than Site 1, when both sites were visited under the same weather conditions on the same day. Water turbidity was measured as a calculation of visible distance underwater at each site on June 27, 2018. This measurement coincided with collection of sediment pipes after they experienced 5 days of sedimentation. Visibility at the mangrove-facing seagrass Site 1 was about 1.3 m, while seagrass Site 2 had a shorter visibility of approximately 0.8 m.

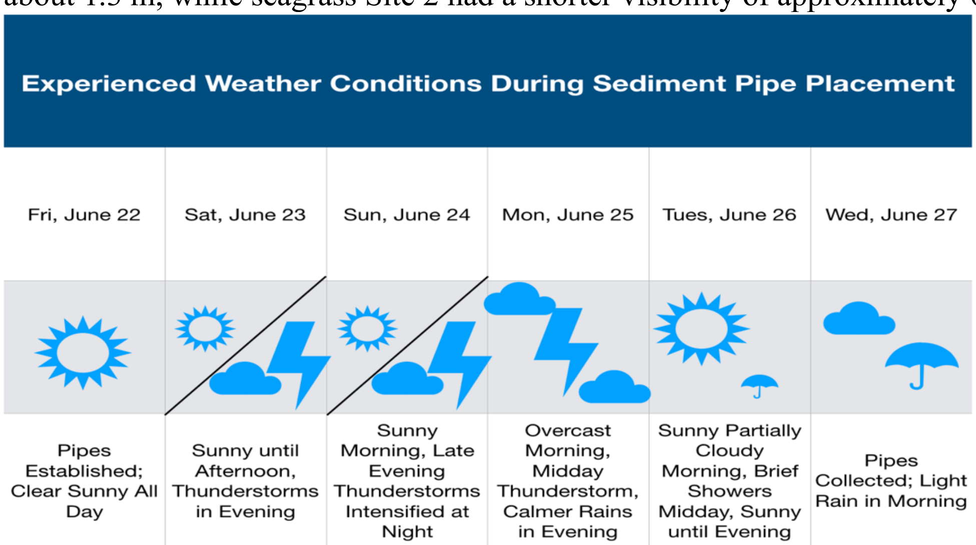

Figure 4: Observations of weather experienced and recorded from work in the field.

Sediment Deposition

All 24 sedimentation pipes were collected on June 27, 2018 after experiencing 5 full days of sediment deposition. Average net dry weights of sediment were calculated by front and back trial at each site. All trials collected and weighed had average dry weights from front pipe groups that were larger than the average dry weights of pipes positioned in the back of the seagrass. At Site 1, the first trial (S1A1) had an average dry weight of 1.70 g for front pipes compared to 1.11 g deposited in back pipes (Table 1). The second Site 1 trial (S1A2) also had an average dry front sediment weight of 1.07 g larger than the average dry back sediment weight of 0.93 g (Table 1). The trials of Site 2 have averages that exhibited the same trend of front sediments weighing more than back sediment collections, but at values 20 to 40 times larger than those found at Site 1. S2A1 had a front sediment average of 45.68 g compared to a 26.62 g average from back sediments, while S2A2 had front and back averages of 46.08 g and 41.16 g respectively (Table 1).

Overall averages for both front and back sediment weights were then calculated for each site and compared graphically. Site 1 front pipes had an overall average of 1.39 g that was slightly higher than the back pipe average of 1.01 g (Figure 5). These averages also have a small standard error of about 0.2 when compared in Figure 5. Site 2 had an overall average of 45.88 g within front pipes compared to 33.89 g found within back pipes (Figure 6). While these sedimentation weights exhibit the same trend as Site 1, with greater sedimentation found in front areas over back areas, the difference between front and back dry weights is larger and also these values have a larger standard error of approximately 12 g (Figure 6). When the values of Site 1 and Site 2 are compared collectively in Figure 7, the greater magnitude of sediment deposited in Site 2 over Site 1 can be clearly visualized. The front pipes of Site 2 received approximately 40 times the average mass of sediments than front pipes in Site 1, and 33 times the average mass of Site 1 sediments when comparing back pipes (Figure 7). This graphical comparison has a larger standard error of about 23 g (Figure 7). This error is over 20 times the size of the average weights found for Site 1.

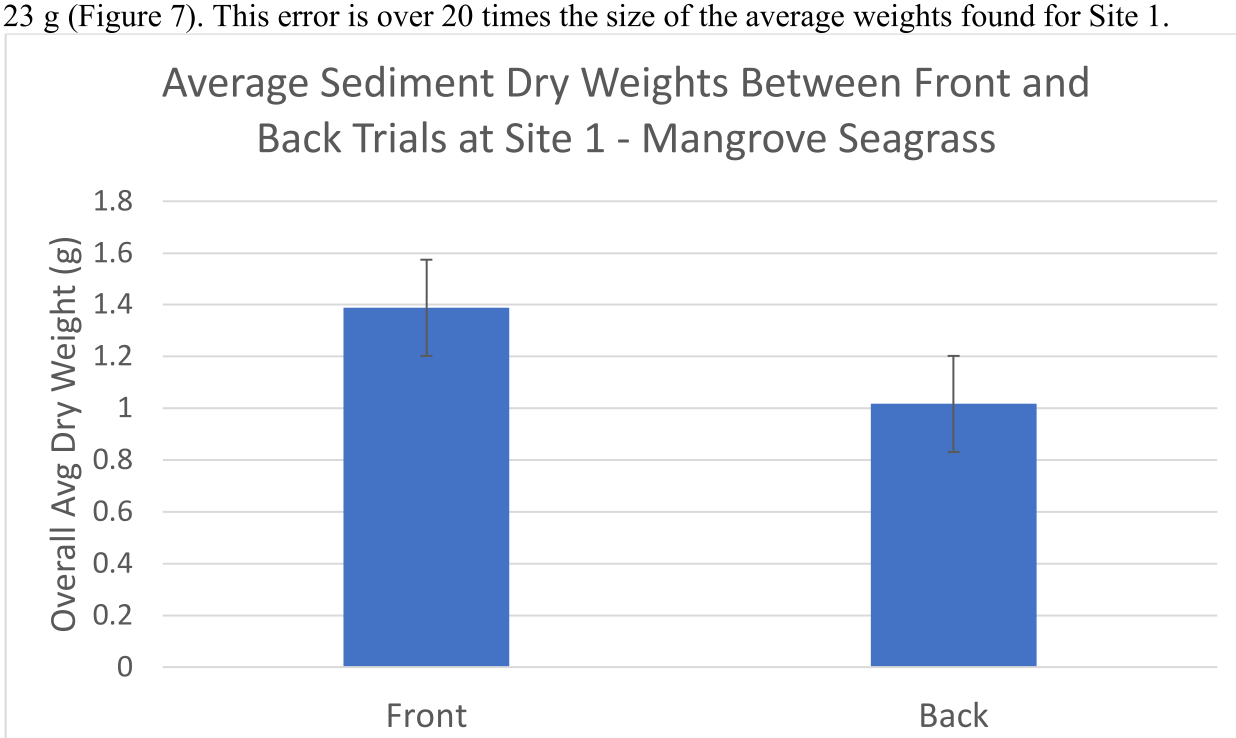

Figure 5: Relative sediment deposition as a measurement of average dry weights for Site 1.

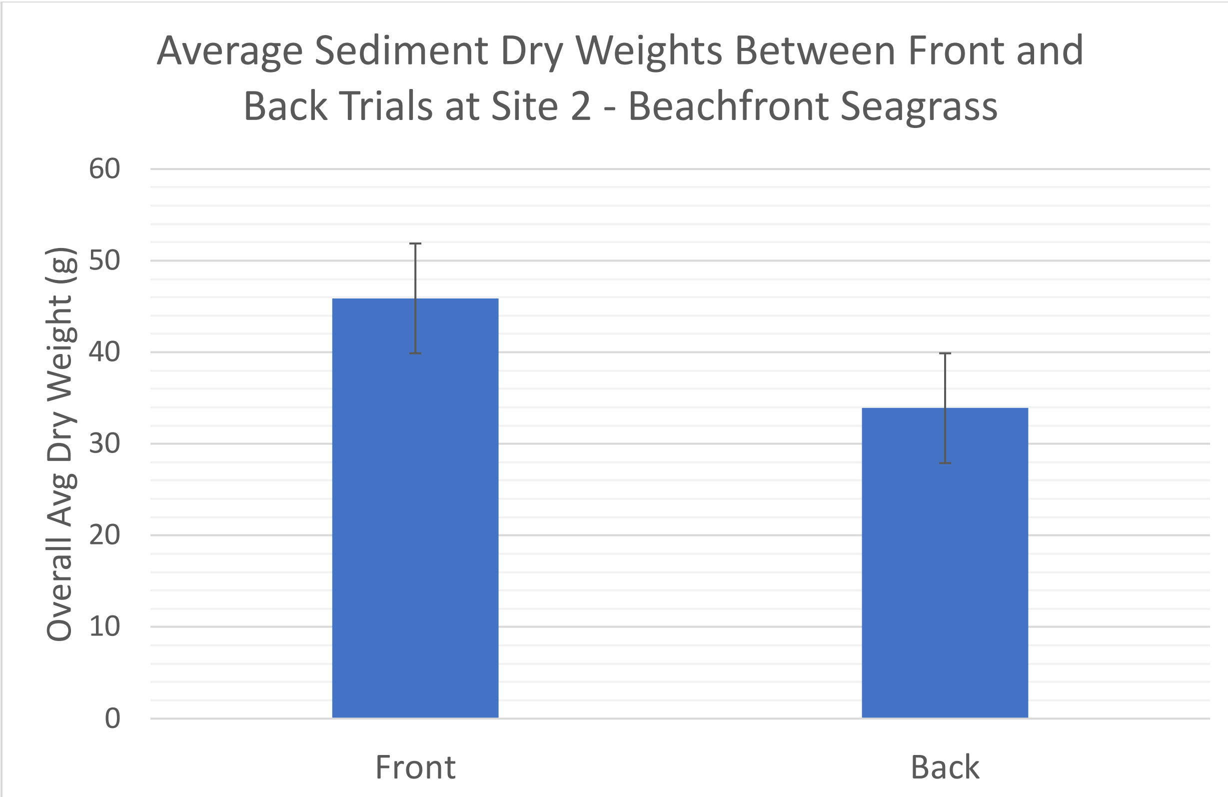

Figure 6: Relative sediment deposition as a measurement of average dry weights for Site 2.

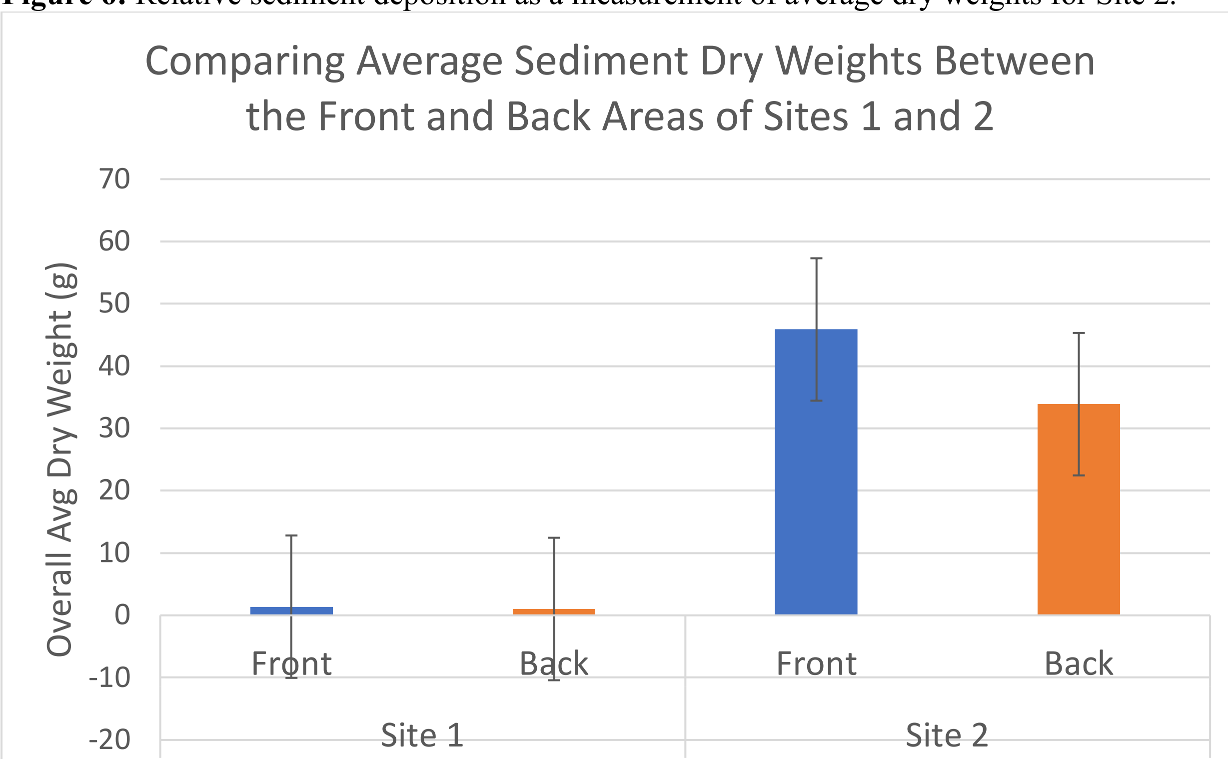

Figure 7: Visual comparison of average sediment dry weights between Sites 1 and 2.

Four two-sample t-tests were performed on front and back pipe sediment weights to evaluate if there was statistically significant difference both within and between seagrass sites. The first t-test comparing the front pipe sediment weights of Site 1 to Site 2 calculated a low two-tailed p-value of 1.58×10^{-8} (Table 2.1) Similarly, a t-test comparing the back sediment dry weights of Sites 1 and 2 yielded a low p-value of 6.22×10^{-6} (Table 2.2). When evaluating difference between the front and back sediment weights within Site 1, a higher p-value of 0.27 was calculated (Table 2.3). The parallel t-test evaluating front and back sediment weights in Site 2 yielded a p-value of 0.01 (Table 2.4).

Sediment Composition

Sediment grains and identification of matter within sediment was qualitatively observed during pipe extraction and filtration. In both sites, filtration of the top water within pipes was relatively clear, with small amounts of floating organic matter. The sediments from Site 1, appeared and dried as a light brown heterogeneous mixture (Figure 8.1). Sediment grains were visibly globular and finer than sand, but not relatively compact. Site 1 pipes contained many amorphous bits of plant tissue, decaying matter, and suspended filaments collectively classified as organic matter. Site 2 sediments were a darker grey and much more homogenous mixture of finer sediments, and were also characterized by a smell of sulfurous soil (Figure 8.2). Less distinct pieces of organic matter could be identified within draining samples, as the finer sediments were compacted closely together. Opportunistic brown algae began to grow primarily inside the pipe of Site 2, and was partially collected within the sediment drainage process of these trials.

Figure 8.1 (Left): Sediment contents of S1 pipe. **Figure 8.2** (Right): Sediment contents of S2 pipe.

Seagrass Bed Measurements

The relative abundance of the two seagrass bed sites was first quantified through a measurement of seagrass density. Both front and back regions of Site 2 exhibited higher densities of seagrass shoots recorded in the quadrat samples. S1 Front had an average density recorded of 6.333 or 6 shoots and S1 Back had an average of 9.67 or 10 shoots per quadrat, while S2 had averages of 17 front and 15.67 or 16 back seagrass per quadrat (Table 3). Based on these average shoot densities by quadrat, it was shown that the back region of Site 1 had a higher seagrass density than the front regions, while Site 2 had a higher seagrass density in the more coastal front than the further back seagrass (Figure 9). However, the values of front and back seagrass densities for each respective site are relatively close and overlap within the margin of standard error, which was calculated to be about 5 seagrass shoots. When using the average shoots per quadrat (200 cm^2) to estimate the number of seagrass within a square meter, the front region of Site 2 had the highest density of 850 shoots while the front of Site 1 had the lowest density at 317 shoots (Table 3).

Two-sample t-tests were also performed to test the statistical significance of the difference in densities between front and back regions, and between sites. The test evaluating differences between the fronts of Sites 1 and 2 calculated a low two-tailed p-value of 7.2×10^{-3}Table 5.1). The test examining difference between the densities of the backs of Site 1 and 2 had a two-tailed p-value of 0.09, but a one-tailed p-value of 0.049 (Table 5.2). Comparing within sites, the test between S1 Front and S1 Back produced a p-value of 0.27 (Table 5.3). The test between S2 Front and S2 Back produced a p-value of 0.61 (Table 5.4).

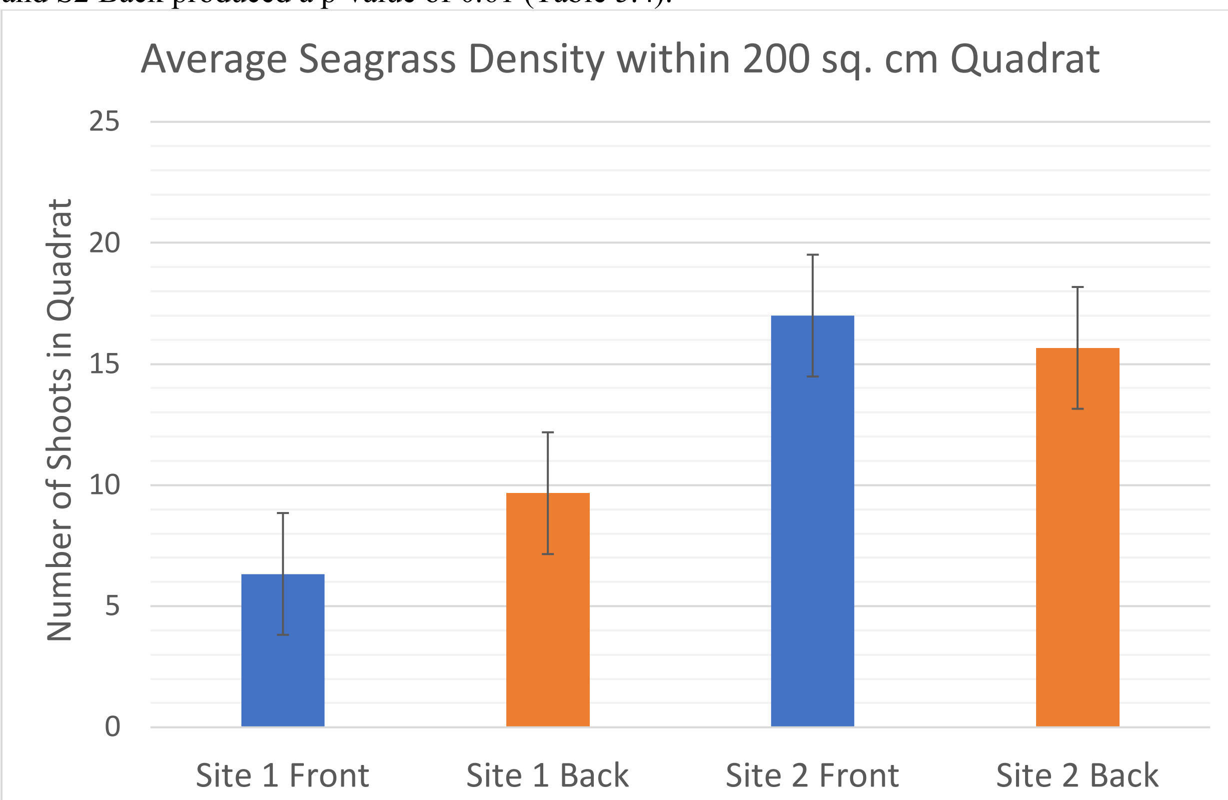

Figure 9: Measuring relative seagrass abundance in different site areas using shoot density.

The net dry weight of *Thalassia testudinum* shoots taken from these quadrat samples was measured as an estimation of seagrass above-ground biomass. Similar to having the lowest seagrass density, the front of Site 1 also contained the least biomass collected from sample quadrats with a mean net dry weight of 4.72 g (Table 4). The front and back areas of Site 2 had close average net dry weights of 6.45 and 6.25 respectively. The back of Site 1 is recorded to have the most average biomass at 10.5 g per quadrat, and this can be extrapolated to 525 g/m^2 (Table 4). Figure 10 shows that Site 1 Back is higher than all other averages, and the average biomass of S1 Front is closer to that of S2 Front and Back than to S1 Back. Two-sample t-tests were performed on the front and back biomass data sets within and between each site, but all tests produced high p-values that cannot be used to provide an explanation of statistical significance.

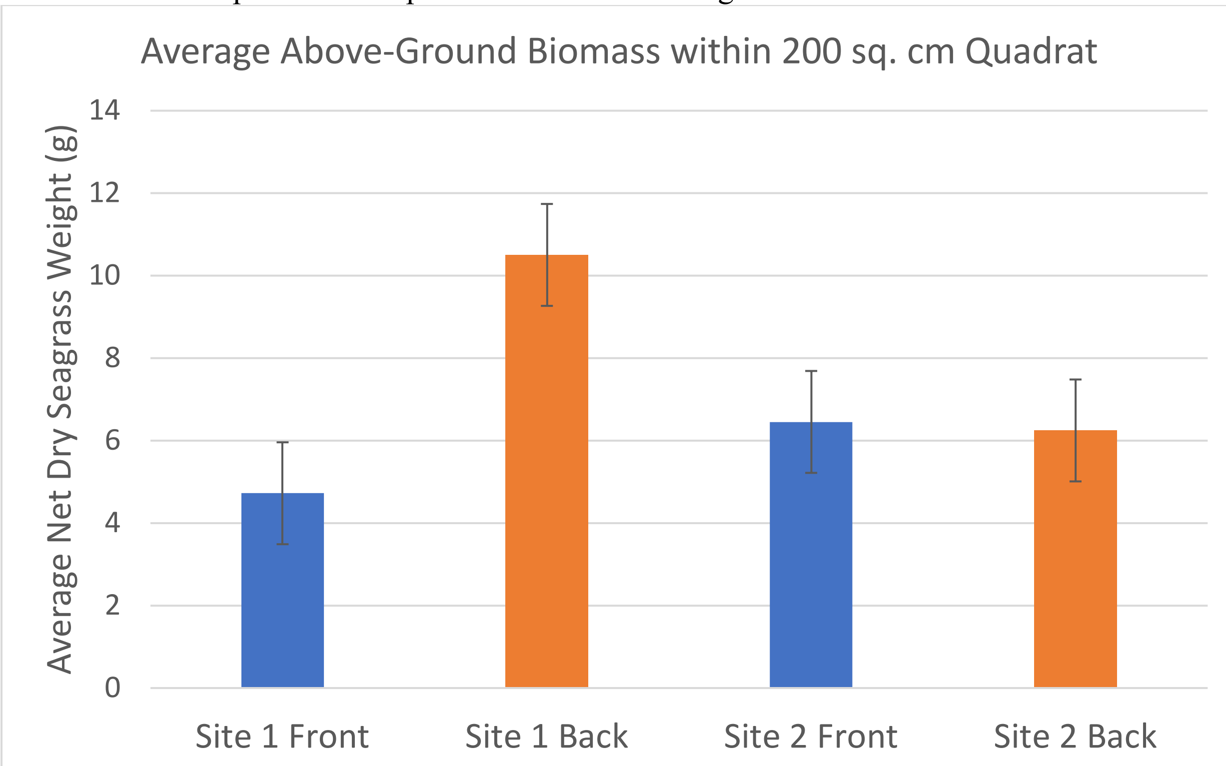

Figure 10: Measuring relative seagrass abundance in different sites using above-ground biomass.

Leaf area and percentage of epiphyte coverage were successfully measured using the 5 randomly taken *T. testudinum* shoots taken from each site. The 5 individual shoots from Site 1 had 13 leaves total that were measured, while the 5 shoots from Site 2 had 12 leaves (Table 6). The average seagrass leaf length of 20.75 cm for Site 1 was larger than the average leaf length of Site 2, which was 17.3 cm (Figure 11). Average widths between the two sites were highly similar, measuring at 0.92 cm in Site 1 and 1.04 cm in Site 2 (Table 7). Average leaf area was shown to be slightly higher in Site 1 at 19.17 cm^2 than Site 2 at 18.33 cm^2 (Figure 12). Site 1 also had a higher amount of leaf area covered in epiphytes, 88%, compared to Site 2 at 74% (Table 7). Sites 1 and 2 had similar percentages of leaves without rounded tips, 62% and 67% respectively, with the plants sampled from Site 2 experiencing slightly more herbivory (Table 8). It was also qualitatively recorded during collection of epiphyte coverage that Site 1 primarily contained large swaths of filamentous algae, and many standing seagrass blades were browning and rotting. Site 2 seagrass samples had less filamentous algae and more visible calcareous epiphytes.

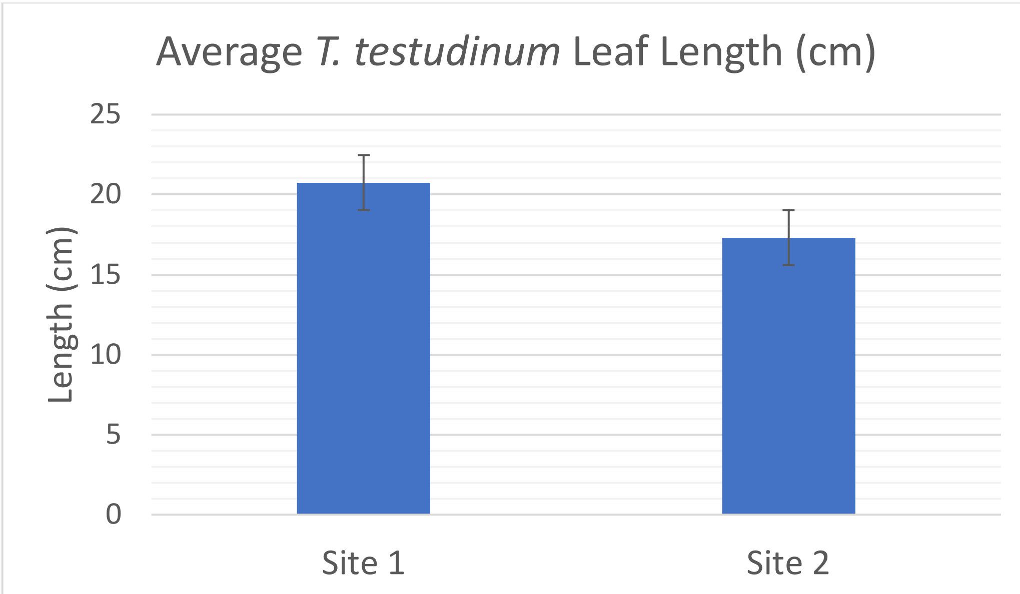

Figure 11: Comparing average seagrass leaf length between sites.

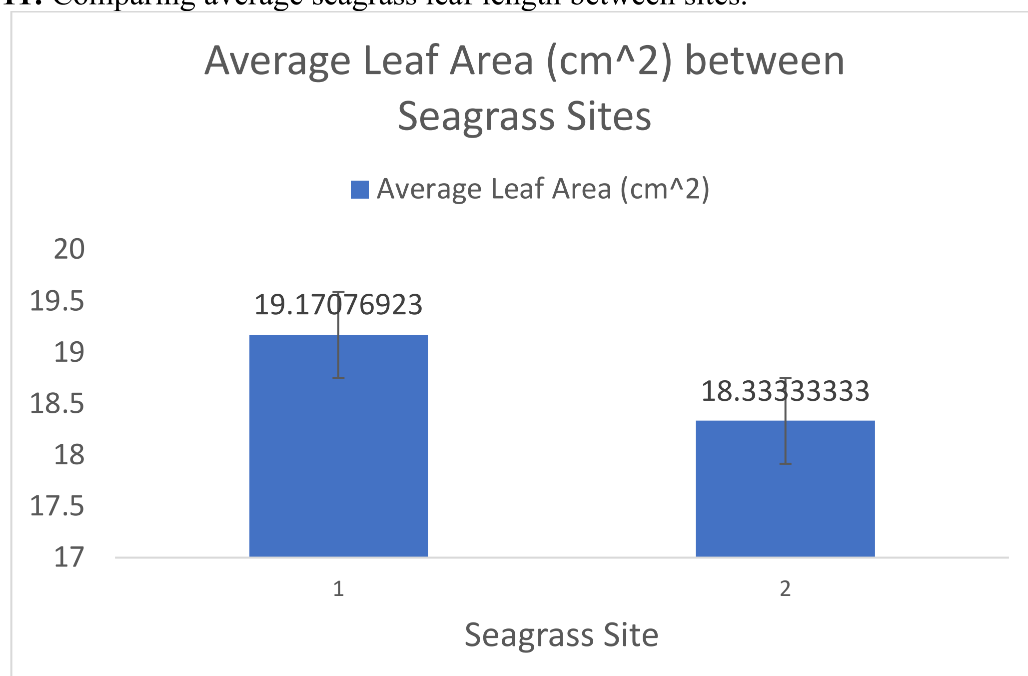

Figure 12: Comparing average seagrass leaf area between sites.

<u>Discussion</u>

Interpretation of Statistical Analysis

The two-sample t-tests performed for sediment deposition weights and seagrass densities are tests that each seek to evaluate whether differences between both front and back regions and between sites are statistically significant, in order to answer the research question of this study with greater certainty. The null hypothesis within each test is that the difference between the regions being compared does not convey significance that is larger than chance alone. Rejecting the null hypothesis accepts the alternate hypothesis that these differences are statistically significant. These statistical inference tests used the alpha threshold of 0.05, meaning any p-value lower than this value rejects the null hypothesis and indicates statistically significant difference.

The t-test comparing the sediment weights found in Site 1 compared to Site 2 had a p-value of 1.58×10^{-8} that is much lower than the threshold of 0.05, rejecting the null hypothesis for this test (Table 2.1). This states that the difference between the greater average of Site 2 front sediment mass over the Site 1 front average is highly statistically significant. Similarly, the comparison of back averages of sediment weight between Sites 1 and 2 produced the low p-value of 6.22×10^{-6}, indicating these sets of data have statistically significant difference (Table 2.2). Table 2.4 produces a p-value of 0.01 that states there is significant difference between the front sediment and back sediment averages of Site 2. Meanwhile, Table 2.3 shows the differences in sediment average between the front and back of Site 1 cannot reject the null hypothesis or be shown as statistically significant.

When analyzing the significance of differences in seagrass density, the comparisons of front and back sites within Site 1 and within Site 2 both yielded high p-values (0.61 for S1 and 0.27 for S2) that exceed the threshold of 0.05 and each fail to convey significance to these differences (Table 5.3; Table 5.4). Comparing the average densities of the front areas in Sites 1 and 2 produced a p-value of 7.2×10^{-3} that states there is significant difference between these densities (Table 5.1). Lastly, the average densities of back regions in Sites 1 and 2 had a two-tailed p-value of 0.09 higher than 0.05, but a one-tailed p-value that was just lower at 0.04 (Table 5.2). This indicates that the specific relationship where Site 2 average back density is larger than the back density of Site 1 is significant.

Differences in Sedimentation – Factors Influencing Deposition and Composition

Results showed that the amount of sediment deposited in the two distinct seagrass beds over the 5 day period studied was dramatically higher in Site 2, which faced coastal beachfront lacking mangroves, compared to Site 1 on the mangrove coast. Both front and back average weights of sediment collected from Site 2 (45.87 g F and 33.89 g B) were multiple times greater than the averages measured in the front and back areas of Site 1 (1.39 g F and 1.02 g B), and these differences were found to be highly statistically significant within two-sample t-tests (Figure 7). These findings suggest two main logical explanations for the differences in the weight of sediment deposition across these two sites. First, it is possible that Site 2 experiences a larger amount of sediment input from the surrounding environment than Site 1 receives. Secondly, the physical and biological conditions of the *Thalassia testudinum* seagrass bed of Site 2 could differ from Site 1 in a way that allows for Site 2 to capture and retain more deposited sediment.

A primary factor that can influence the difference in seagrass sedimentation across the two sites is the different terrestrial habitat these sites face on the coast. Pipes were established in seagrass at Site 1 that faced a dense *Rhizophora mangle* mangrove coast, and visual observations showed no signs of anthropogenic infrastructure that would make this forest partially cleared. Established *R. mangle* forests have been shown in scientific literature to provide the ecosystem service of retaining terrestrial runoff and nutrients within anaerobic peat bogs, created by the tangled roots that limit water and sediment movement (Lovelock et. al. 2005). It is possible that large amounts of terrestrial runoff that could be deposited as sediment in the seagrasses at Site 1 were instead captured and held within the mangrove forest, leading to the low average weight of sediment collected in these pipes. Meanwhile, Site 2 seagrass faced a beachfront that was partially cleared of its forests for residential development. By not being adjacent to dense coastal mangroves, the seagrass meadows of Site 2 do not experience the consequences of mangrove sediment retention and likely receive more runoff from terrestrial inputs. This literary evidence would support the greater weight of sediments received in all pipe trials of Site 2 compared to Site 1. Granek & Ruttenberg (2008) also found that coasts facing mangroves that were historically cleared received more sediment than coasts in front of intact mangroves, further supporting the trends found in this sedimentation study. Coastal areas where mangroves were historically removed also contained less organic matter in oceanic sediments, which is similar to the observations of sediment composition found between Sites 1 and 2 (Granek & Ruttenberg 2008). Mangrove-facing Site 1 was noted to have more macroscopic pieces of organic decaying tissue than beachfront Site 2, which had dark, fine, and compact mineralized sediments (Figures 8.1 and 8.2). 'Historically cleared' in this study indicates that mangroves are currently growing after past clearing events in the area (Granek & Ruttenberg 2008). Site 2 can likely be considered a 'currently cleared' area rather than a 'historically cleared' forest, and as such should experience even more sedimentary runoff. This literary evidence again supports the pattern that showed greater magnitudes of sediment deposited in Site 2 over Site 1.

The weather conditions experienced during the 5 days of pipe field exposure likely had a significant impact on the amount of sediment moved through erosion and runoff during this period, as well as the intensity of water currents that could move these inputs into each seagrass site. The end of June is in the middle of the Panamanian wet season, and while Bocas del Toro is outside of the immediate hurricane belt, studies have shown Caribbean hurricanes to influence tropical thunderstorms that cause large amounts of sedimentation to fall in coastal seagrass sites (Lovelock et. al. 2005; Cabaço et. al. 2008). The majority of days that pipes were established experienced rains and thunderstorms that increase freshwater runoff and the movement of larger tidal waves that can transport sediment (Figure 4). Collected results for water turbidity also showed that Site 2 had a lower visibility of 0.8 m compared to 1.3 m at Site 1. Greater water turbidity can be caused by a greater amount of sediments suspended in the water column, and this could also relate to how Site 2 experienced more sediment deposition than Site 1. However, both of these levels of turbidity are also likely elevated by the constant turbulence rainstorms create by intensifying wind, waves, and other factors that uplift sediment in the water column (Newell & Koch 2004).

Seagrass blades like *T. testudinum* with large leaf area collide with incoming water currents and their sediments reducing their energy and increasing sediment deposition (Ondiviela et. al. 2014). While Site 1 *T. testudinum* was shown to have a slightly larger leaf area (19.17 cm^2) than Site 2 samples (18.33 cm^2), Site 2 had a larger seagrass density at both front and back sites that was statically significant. These trends would suggest that Site 2 seagrass would be able to collide with and induce the deposit of more sediments from intense storm currents, and this would be supported by the greater amount of sediment collected and weighed from Site 2 pipes. Additionally, another ecosystem service that mangrove coastlines provide is protection from storms and coastal erosion (Donato et. al. 2011). Waves were qualitatively observed to be continually less intense at Site 1 than Site 2, and water movement could be attenuated by the mangrove coastline of Site 1 compared to the cleared Site 2 beachfront. Less intense water movements also move less sediment smaller distances, and this scientific process would correspond with the much lower average weights of sediments deposited in both the front and back of Site 1 compared to Site 2.

The research question also asks whether there is a difference in the amount of sediment deposited within the front of coastal seagrass or back further into the seagrass meadow. Both Sites 1 and 2 exhibited the same trend where front coastal seagrass areas received more sediment than back seagrass regions. Because the front seagrasses are closer to the intersection between the terrestrial and oceanic coastline, it is possible that they are the first seagrass shoots to encounter sediment from both terrestrial runoff and erosion. Back seagrass regions would be the first areas to receive sediment moving from oceanic water currents, but the evidence in this study would suggest that deposition at the coast is greater than deposition in the deeper portions of the seagrass bed. Results indicated that at Site 1 the difference between average sediment weights (1.39 g F and 1.02 g B) was too small to reject the null hypothesis and convey statistical significance in a two-sample t-test. Meanwhile, the difference between average sediment weights at Site 2 (45.87 g F and 33.89 g B) was calculated to be statistically significant. As stated earlier, greater wave energy culminates at the collision of terrestrial and ocean shoreline, and tides have been shown to be stronger with the absence of mangroves (Donato et. al. 2011; Kaufmann and Thompson 2005). This evidence would support the larger difference in sediment weights between the front and back of Site 2, because the larger and more intense tidal energy this site received on a cleared beachfront coast would favor greater sedimentation in front seagrass areas.

Comparative Synthesis of Seagrass Data

Calculations of *T. testudinum* individual density showed that both front and back regions of Site 2 seagrass were greater than Site 1 densities. T-tests between the two sites showed that differences were statistically significant, indicating there are likely environmental factors beyond chance that support a higher density of Site 2 *T. testudinum* than at Site 1 (Table 5.3 and Table 5.4). The greatest seagrass densities were found around pipes established in Site 2, and these corresponded with the areas where the most sediment was deposited and weighed. By having a greater density, seagrasses would have more collective leaf area per square meter that can act as a biological barrier which collides with sediment moving through incoming currents (Ondiviela et. al. 2014). When comparing densities between the front and back regions of each site, these results could not convey statistically significant difference (Table 5.1 and Table 5.2). This is likely caused by the methodology of defining front and back seagrass trials, which were only set up 15 m apart from one another within the seagrass bed. This distance was too short for depth to substantially change in a way that would influence differences in sunlight or salinity. Literary evidence states that the particular physiology of individuals within a seagrass species can be dictated by the immediate physical and biochemical conditions it is exposed to, particularly light and salinity (López-Calderón et. al. 2013). Therefore, because front and back trials were in such a close area, it is likely that seagrass growth and density should be relatively similar within each site.

Greater water turbidity can limit the density and photosynthetic growth of seagrasses like *T. testudinum* by limiting the amount of sunlight their leaves can receive, or by providing nutrients for opportunistic algae to outcompete them (Newell & Koch 2004). This trend found in the scientific literature was not supported by the findings of this study. Site 2 had lower secchi visibility at 0.8 m on the day of pipe collection than Site 1 had (1.3 m), but the seagrasses in Site 2 quadrats were denser than Site 1. However, it is likely that these measurements of turbidity were directly impacted by the multiple rainstorms that went through the area in the prior week. This measurement of turbidity therefore may not be reflective of the long-term water quality conditions that influence the density of *T. testudinum* growth in these sites.

Calculated above-ground biomass showed that the front and back regions of Site 2 had similar dry *T. testudinum* masses (Figure 10). This corresponds with the similar trend that showed the front and back regions of Site 2 to have a very similar density of individual shoots. While Site 1 had lower seagrass densities than Site 2, and Site 1 F had the lowest biomass recorded at 4.72 g per quadrat, Site 1 B had the largest recorded biomass at 10.5 g. This is the only outlier biomass data point that does not correspond loosely with density data. A sample that has a greater density of individuals within a quadrat should also have a larger biomass corresponding to the number of individuals, and it is likely that Site 1 B data points experienced substantial outside error that changed weight measurements. These above-ground biomass calculations can be used as an indicator of seagrass abundance that represents the amount of living tissue that is within an area and anchoring sediments with its below-ground roots (Van Tussenbroek et. al. 2014). With more anchoring tissue structure in the ground, less sediment should be able to be moved by erosion and redeposited in the same site (Potouroglou et. al. 2017). The sediment deposition results of this study are likely influenced by the equilibrium between seagrass sediment-collision and anchoring of sediments. At the same time sediment deposition is impacted by the surrounding habitat characteristics that vary how inputs move into the seagrass through weathering, precipitation, and tidal erosion.

Similar percentages of epiphyte coverage (S1 88% and S2 74%) as well as herbivory inferred from nonrounded tips (S1 62% and S2 67%) were also recorded in the two seagrass beds. These results suggest that each of these two sites house relatively similar amounts of epiphyte habitat and subsequently experience similar amounts of herbivorous control. But when taking density and above-ground biomass into account, results would suggest Site 2 has denser seagrass beds that can support the habitat of more epiphytes per square meter. Observational data also showed that Site 1 epiphytes were dominated by filamentous algae compared to the calcareous epiphytes that were dominant in Site 2. Opportunistic algae has been shown to overwhelm seagrass and kill off rhizomatic colonies by blocking their photosynthetic capability (Albis-Salas & Gavio 2011). It is possible that this filamentous algae covers *T. testudinum* leaves extensively and makes it more challenging to grow in Site 1, leading to the lower density of this plant when compared to Site 2.

Lastly, it is also important to consider that while these sampling methods quantified only the density and subsequent above-ground biomass of *Thalassia testudinum* plants, the seagrass meadows of both sites were not homogeneous. Both Sites 1 and 2 had other types of species that composed the vegetation of each seagrass bed, and also contribute to the density and above-ground biomass that the area holds. In the quadrats of both sites, *Syringodium filiforme* shoots were found to live prolifically amongst the *T. testudinum* plants. This is the second most common Caribbean seagrass after *T. testudinum*, and although it has a thinner physiology it can pack densely into small spaces (Van Tussenbroek et. al. 2014). Additionally, while Site 1 had lower *T. testudinum* density than Site 2, only quadrats sampled in Site 1 had substantial macroalgae growing at the bases of these plants. This macroalgae could possess an antagonistic relationship with *T. testudinum* colonies, and be a contributing factor that resulted in the lower recorded density for Site 1.

Potential Sources of Error

Due to the innumerable amount of variables that can be identified within a living, interconnected, and dynamic coastal marine ecosystem, there are many areas in which sampling methods can have potential sources of error. Sediment pipe structure was envisioned and built in a way that left the pipe somewhat imbalanced. One fastening rebar was used to hold each pipe into the sediment, which led to this side of the pipe having more weight on it. This caused the angle of the pipes to become skewed as they stayed situated in the seagrass bed. Unstandardized orientation of the pipes could have minor influences on how sediment falls into the pipes, with consideration to the direction water currents move in the area. Error could have also been created because some pipes were not as securely fastened in the seagrass bed and fell over. Field notes recorded that at S1 pipes were encountered knocked over 5 times (2 F, 3 B) while S2 pipes were found horizontal 7 times (5 F, 2 B). The increased number of times front pipes fell compared to back pipes at Site 2 could contribute to the increased sediment weights they had over back pipes. However, pipe displacement would be primarily influenced by water currents and wave energy, which was noted to be more intense for the front region of S2 when discussing factors that move sediments. The drastic difference in sediment weights measured in all S2 pipes compared to S1 pipes, despite the relatively similar number of times pipes were knocked over, indicates that the angle and movement of pipes likely do not have large impacts on the data found. Thirdly, the rainstorms that were interspersed throughout the week of study influenced the ability for both seagrass and sediment samples to dry. Samples were originally envisioned to dry outside in a plastic solar oven, but this structure got overrun with rainwater before samples could be placed inside. This method was replaced by drying samples inside, but the inside area could not guarantee that light and heat was received equally to each sample. Cloudier skies also limited the amount of sunlight available for drying. This likely led to more water being retained in samples than expected and would make some weights skewed higher than they actually were, and is the primary variable suspected for the anomaly of exceedingly high Site 1 B seagrass biomass. Retention of extra water in sediments would increase the weight they measured as, but this would also offset the weight of any sediment lost during the draining process. These errors could be mitigated in future studies by choosing to use more stable pipe configurations, as well as performing types of sampling methods or equipment that are more resilient to weather change.

Conclusion

This study was developed in order to understand the differences in sediment deposition and seagrass abundance between two *Thalassia testudinum* sites, and how the unique habitat differences, physical processes, and biological actors at each site could potentially influence the way seagrasses both receive and retain sediments. Analysis of results concluded that the site facing a dense and uncleared mangrove forest had seagrasses that experienced low amounts of sediment deposition over a 5 day period, while the site facing a coastal beachfront where forests had been partially cleared received much larger amounts of sediment deposition containing more inorganic matter. This study hypothesizes that these differences in sediment deposition were caused in part by the presence or absence of mangrove forests on the terrestrial coastline. The environmental conditions of the surrounding habitat are believed to be highly influential on the amount of sediment a seagrass bed receives, especially under physically stressful conditions like routine rainstorms. The beachfront Site 2 was also shown to have a higher density of *T. testudinum* individuals compared to the mangrove Site 1. This relationship implicates that the more dense seagrass beds were able to retain more sediments for deposition through attenuation of water flow. The most dense Site 2 samples also had substantial amounts of above-ground biomass compared to most less dense Site 1 samples. Since more living biomass suggests a greater ability for seagrass to anchor sediments already in the substrate, it is less likely for previously deposited sediment to be susceptible to erosion. This data would reinforce the notion that the beachfront region likely receives more types of sediment inputs for deposition than the mangrove site. However, the entire span of plant and algal organisms that compose the total density and biomass of seagrass beds was not measured, only the impact of the dominant *T. testudinum* species. Future research could include a more comprehensive knowledge of the number of other plants and macroalgae growing within each of these sites. This information could be used to more accurately understand the overall density that is engaging with water currents and influencing sedimentation. Other research approaches could be used to quantify sediment composition in more detail, such as by grain size or flammable carbon content. Sediment deposition could also be measured in longer term studies that collect sediment at multiple time points in order to calculate sedimentation rate and understand annual trends in sediment flows.

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Appendix

Table 1: Net Dry Weight (g) of Sediments Deposited at Site 1 and Site 2

Pipe Name	Empty Tin (g)	Empty Coffee (g)	Wet Wt. (g)	Total Dry Wt. (g)	Net Dry Wt. (g)	Average Trial Net Dry Wt.
S1A1F1	2.23	0.93	8.94	5.12	1.96	
S1A1F2	1.45	0.61	7.68	3.92	1.86	
S1A1F3	1.51	0.61	5.41	3.41	1.29	1.703333333
S1A1B1	1.89	0.93	6.44	4.56	1.74	
S1A1B2	1.98	0.92	6.86	3.43	0.53	
S1A1B3	1.71	0.86	6.03	3.62	1.05	1.106666667
S1A2F1	1.59	0.84	6.21	4.02	1.59	
S1A2F2	1.75	0.86	4.72	2.89	0.28	
S1A2F3	0.6	0.79	4.92	2.74	1.35	1.073333333
S1A2B1	1.23	1.69	7.99	4.33	1.41	
S1A2B2	0.89	0.96	4.55	2.36	0.51	
S1A2B3	0.94	0.87	4.98	2.67	0.86	0.926666667
S2A1F1	6.68	0.98	63.09	56.21	48.55	
S2A1F2	2.23	0.91	51.23	42.34	39.2	
S2A1F3	3.35	0.68	60.81	53.31	49.28	45.67666667
S2A1B1	1.76	0.77	37.84	29.35	26.82	
S2A1B2	1.6	1.27	41.32	34.79	31.92	
S2A1B3	1.18	0.96	33.38	23.27	21.13	26.62333333
S2A2F1	2.52	1.31	60.59	48.39	44.56	
S2A2F2	3.46	1.04	59.91	48.29	43.79	
S2A2F3	2.46	1.34	58.67	53.68	49.88	46.07666667
S2A2B1	4.2	1.54	45.76	41.18	35.44	
S2A2B2	4.39	1.3	56.31	52.26	46.57	
S2A2B3	1.71	1.46	57.49	44.63	41.46	41.15666667

Table 2.1: Two-Sample t-test Assuming Eq. Var. Between Front Site Sediments		
	Site 1 Front	*Site 2 Front*
Mean	1.38833333	45.8766667
Variance	0.36589667	17.0843467
Observations	6	6
Pooled Variance	8.72512167	
Hypothesized Mean Difference	0	
df	10	
t Stat	-26.086813	
P(T<=t) one-tail	7.8853E-11	
t Critical one-tail	1.81246112	
P(T<=t) two-tail	1.5771E-10	
t Critical two-tail	2.22813885	

Table 2.2: Two-Sample t-test Assuming Eq. Var. Between Back Site Sediments		
	Site 1 Back	*Site 2 Back*
Mean	1.01666667	33.89
Variance	0.23942667	87.43464
Observations	6	6
Pooled Variance	43.8370333	
Hypothesized Mean Difference	0	
df	10	
t Stat	-8.5997097	
P(T<=t) one-tail	3.1088E-06	
t Critical one-tail	1.81246112	
P(T<=t) two-tail	6.2176E-06	
t Critical two-tail	2.22813885	

Table 2.3: Two-Sample t-test Assuming Eq. Var. Between Site 1 Front and Back		
	Site 1 Front	*Site 1 Back*
Mean	1.38833333	1.01666667
Variance	0.36589667	0.23942667
Observations	6	6
Pooled Variance	0.30266167	
Hypothesized Mean Difference	0	
df	10	
t Stat	1.17013382	
P(T<=t) one-tail	0.13453926	
t Critical one-tail	1.81246112	
P(T<=t) two-tail	0.26907852	
t Critical two-tail	2.22813885	

Table 2.4: Two-Sample t-test Assuming Eq. Var. Between Site 2 Front and Back		
	Site 2 Front	*Site 2 Back*
Mean	45.8766667	33.89
Variance	17.0843467	87.43464
Observations	6	6
Pooled Variance	52.2594933	
Hypothesized Mean Difference	0	
df	10	
t Stat	2.87194725	
P(T<=t) one-tail	0.0083066	
t Critical one-tail	1.81246112	
P(T<=t) two-tail	0.01661321	
t Critical two-tail	2.22813885	

Table 3: Seagrass Density within 20x10 cm Quadrats at Sites 1 and 2

Quadrat Name	Number of Shoots	Average Density by Trial	Estimated Indviduals/sq. m
S1Q1F	8	6.333333333	316.6666667
S1Q2F	4		
S1Q3F	7		
S1Q1B	14	9.666666667	483.3333333
S1Q2B	8		
S1Q3B	7		
S2Q1F	20	17	850
S2Q2F	14		
S2Q3F	17		
S2Q1B	15	15.66666667	783.3333333
S2Q2B	19		
S2Q3B	13		

Table 4: Seagrass Above-Ground Biomass calculated from 20x10cm Quadrats at Sites 1 and 2

Quadrat Name	Empty Tin	Total Biomass (g)	Net *T. testudinum* Dry. Wt.(g)	Average Above-Ground Biomass (g)	Estimated g/sq. m
S1Q1F	2.33	7.69	5.36	4.723333333	236.1666667
S1Q2F	5.01	5.63	0.62		
S1Q3F	3.08	11.27	8.19		
S1Q1B	1.8	16.56	14.76	10.50333333	525.1666667
S1Q2B	2.27	11.68	9.41		
S1Q3B	2.37	9.71	7.34		
S2Q1F	3.34	13.28	9.94	6.453333333	322.6666667
S2Q2F	2.54	6.82	4.28		
S2Q3F	2.28	7.42	5.14		
S2Q1B	2.33	8.96	6.63	6.246666667	312.3333333
S2Q2B	2.81	10.4	7.59		
S2Q3B	2.47	6.99	4.52		

Table 5.1: Two-Sample t-test Assuming Eq. Var. Between Front Site Densities		
	Site 1 Front	*Site 2 Front*
Mean	6.33333333	17
Variance	4.33333333	9
Observations	3	3
Pooled Variance	6.66666667	
Hypothesized Mean Difference	0	
df	4	
t Stat	-5.0596443	
P(T<=t) one-tail	0.00359116	
t Critical one-tail	2.13184679	
P(T<=t) two-tail	0.00718233	
t Critical two-tail	2.77644511	

Table 5.2: Two-Sample t-test Assuming Eq. Var. Between Back Site Densities		
	Site 1 Back	*Site 2 Back*
Mean	9.66666667	15.6667
Variance	14.3333333	9.33333
Observations	3	3
Pooled Variance	11.8333333	
Hypothesized Mean Difference	0	
df	4	
t Stat	-2.136207	
P(T<=t) one-tail	0.04975551	
t Critical one-tail	2.13184679	
P(T<=t) two-tail	0.09951103	
t Critical two-tail	2.77644511	

Table 5.3: Two-Sample t-test Assuming Eq. Var., Front vs. Back Site 1 Densities		
	Site 1 Front	*Site 1 Back*
Mean	6.33333333	9.6667
Variance	4.33333333	14.3333
Observations	3	3
Pooled Variance	9.33333333	
Hypothesized Mean Difference	0	
df	4	
t Stat	-1.3363062	
P(T<=t) one-tail	0.12620027	
t Critical one-tail	2.13184679	
P(T<=t) two-tail	0.25240055	
t Critical two-tail	2.77644511	

Table 5.4: Two-Sample t-test Assuming Eq. Var., Front vs. Back Site 2 Densities		
	Site 2 Front	*Site 2 Back*
Mean	17	15.6667
Variance	9	9.3333
Observations	3	3
Pooled Variance	9.16666667	
Hypothesized Mean Difference	0	
df	4	
t Stat	0.53935989	
P(T<=t) one-tail	0.30912982	
t Critical one-tail	2.13184679	
P(T<=t) two-tail	0.61825963	
t Critical two-tail	2.77644511	

Table 6: Epiphyte Coverage and Leaf Area Data Collected from Sites 1 and 2

	Plant Number	Leaf Number	Length (cm)	Width (cm)	First Epiphyte	Rounded Tip	Leaf Area cm^2
Site 1		Leaf 1	23.1	0.7	21.1	yes	16.17
		Leaf 2	20.4	0.7	19	no	14.28
	Plant 1	Leaf 3	8.8	0.8	2.2	yes	7.04
		Leaf 1	28.7	0.9	27.9	no	25.83
		Leaf 2	28.2	1	22.9	yes	28.2
	Plant 2	Leaf 3	14.5	1	14	no	14.5
		Leaf 1	26.3	0.9	26.1	no	23.67
	Plant 3	Leaf 2	18.5	1	15.8	no	18.5
		Leaf 1	27.5	1	24.8	no	27.5
		Leaf 2	32.6	1	32.6	no	32.6
	Plant 4	Leaf 3	3.2	1.1	0	yes	3.52
		Leaf 1	32.1	1	31.1	no	32.1
	Plant 5	Leaf 2	5.9	0.9	0	yes	5.31
Site 2		Leaf 1	16.4	1	14.6	no	16.4
		Leaf 2	25	1	19.4	no	25
	Plant 1	Leaf 3	16.2	0.7	12.7	yes	11.34
		Leaf 1	18.5	1	11.5	no	18.5
	Plant 2	Leaf 2	17.3	1.1	16.9	no	19.03
		Leaf 1	17.7	1	17.2	no	17.7
	Plant 3	Leaf 2	12.3	1	5.7	yes	12.3
		Leaf 1	29.2	1.2	29.8	no	35.04
		Leaf 2	5.7	1.1	0	yes	6.27
	Plant 4	Leaf 3	4.9	1	0	yes	4.9
		Leaf 1	29.4	1.2	17.7	no	35.28
	Plant 5	Leaf 2	15.2	1.2	7.4	no	18.24

Table 7: Calculated Average Lengths, Widths, and Areas from Epiphyte Data within Table 6

Site	Average Length (cm)	Average Width (cm)	Average Leaf Area (cm^2)	Total Length	Total Epiphyte Length	Percent Epiphyte Cover
1	20.75384615	0.923076923	19.17076923	269.8	237.5	0.8802 or 88%
2	17.31666667	1.041666667	18.33333333	207.8	152.9	0.7358 or 74%

Table 8: Herbivory Estimated from Rounded Tip Data

Site	# Rounded	# Non-Rounded	Percent Herbivory
1	5	8	0.6153 or 62%
2	4	8	0.6667 or 67%